EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

An implanted ^{228}Ra source for response characterization of bolometers

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Abstract

TeO_2 crystals are used as bolometers in experiments searching for Double Beta Decay without emission of neutrinos. One of the most important issues in this extremely delicate kind of experiments is the discrimination of the background from the real signal. A deep knowledge of the bolometric response to α particles is therefore needed to recognize and discard them, since it has been proven that α surface contamination could be a major contribution in our background budget. We would like to use ISOLDE's capability of implanting ^{228}Ra to make a long-lived source feeding several monochromatic alphas and recoiling nuclei, with little or no α-peak broadening due to the source itself, for tests of our detectors in Milano and Gran Sasso INFN National Lab

Requested shifts: Implantation on host material (Au or Pt would be the best, to avoid contamination, corrosion and oxidation) of radioactive ^{228}Ra ions up to 5 kBq activity (no special request for handling and transportation after irradiation for the Italian law): 3 shifts for a total of 24 h beam at 2x10^7 ions/sec at minimum beam energy acceptable (10 kV?), to implant the ions at a very shallow depth (of the order of 50 nm in Au).

1 Introduction and motivation

Bolometric detectors [1] are used in particle physics experiments to search for rare events like Neutrinoless Double Beta Decay (DBD) and Dark Matter (DM) interactions. They are sensitive calorimeters operated at ~10 mK that measure the temperature rise produced by the energy deposited in particle interactions.

An array of bolometers made of TeO_2 crystals will be used in the CUORE experiment [2] to search for the DBD of ^{130}Te. A precise knowledge of the response function of these bolometers to each species of particles (β, γ and α) is important for background rejection. Indeed, a sizeable fraction of the background in the DBD Region of Interest (RoI), that for ^{130}Te is around 2.5 MeV, is due to degraded α particles that loose part of their energy in the detector support structure and the rest in a single bolometer, mimicking a signal event [3].

While the response of TeO_2 crystals to γ interactions up to 2.6 MeV is well known from the routine calibrations performed with ^{232}Th radioactive sources, there are still relevant items that should be addressed for α particles. The most important are the Quenching Factor (QF), the relative energy resolution and its dependence on energy and, finally, possible signal shape differences with respect to β/γ interactions, particularly in the region where the signal is expected.

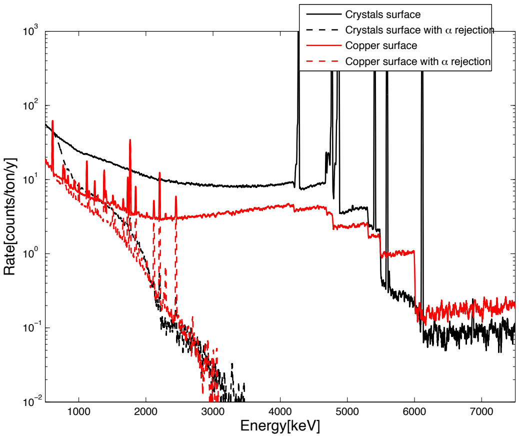
The QF is defined as the amplitude ratio between the signal produced by an α particle and the one produced by an electron depositing the same energy in the detector. It is expected to be very close to unity in thermal detectors since any kind of energy deposition should be converted into heat. It has been measured in the past [3, 4], but with not completely compatible results and a confirmation is now requested because several improvements in our bolometers have been implemented and a better sensitivity can be now reached.

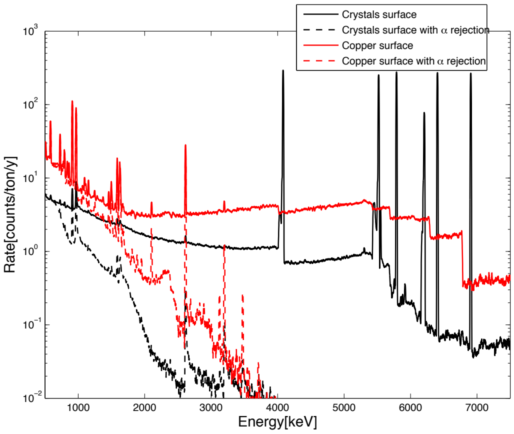
Moreover, there are interests for the use of other crystals for DBD studies with bolometers, particularly scintillating crystals, for which the QF measurement and the signal shape study are even more important [5].

It is extremely important that the radioactive source used for these tests will not deteriorate consistently the optimal energy resolution of bolometers, that for 5 MeV α particles is easily less than 5 keV, by intrinsic line broadening. For this reason any kind of chemical deposition, electric deposition or diffusion is to be avoided. The radioactive source that could be obtained with ISOLDE, where the ions are instead implanted in a shallow depth, is therefore unique and very precious for our studies.

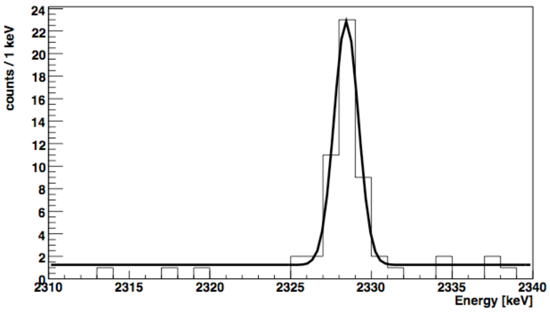
2 Status of the research

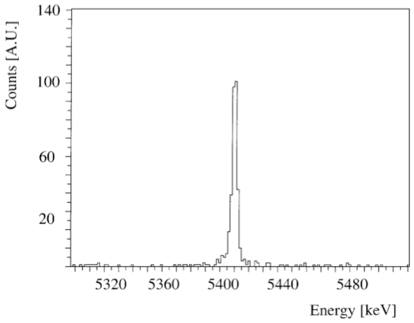
In the following plots you can see the simulation of a contamination in ^{238}U (left) or ^{232}Th (right) in our crystals or in the Cu frames supporting our detectors without (solid histograms) or with α contribution rejection [6]. A gain in the background of 2 orders of magnitude in our ROI could come from the discrimination of α decays, making studies on this field very appealing.





In the left and right plots hereafter you can appreciate the good energy resolution that our bolometers can have for internal α contaminations at 2.3 MeV (FWHM 1.8 keV) [4] and at 5.4 MeV (FWHM 3.2 keV) [7].





With such a good energy resolution it is clear that we would like to have at our disposal a very high quality α source. Very superficial implantation is needed to obtain an almost ideal delta-like calibration α-source, much better than what is available on the market, where at the very best a peak broadening of 20 keV is proposed [8].

3 Experimental set-up in Italy

Since bolometers are quite slow detectors (decay time 0.2 s typically), the 5 kBq ^{228}Ra source is not supposed to be used right in front of our crystals inside the cryostat, but to prepare α calibration sources of no more than 5 Bq activity whenever needed.

^{228}Ra is the daughter nucleus of ^{232}Th, which is the parent nucleus of one of the natural radioactive chains. Since ^{228}Ra is β decaying into ^{228}Ac, which then β decays in ^{228}Th, we will be able to implant ^{224}Ra nuclei produced by the α decay of ^{228}Th on metallic foils, provided they are placed sufficiently near the ISOLDE source under vacuum for a reasonable time.

At the beginning the activity of ^{228}Th will be quite low in the ISOLDE source, but already after 1 month from the implantation of ^{228}Ra it will have an activity of the order of 200 Bq, and from our past experience with a similar source prepared several years ago in the same way, we are confident to be able to prepare our metallic foils with a reasonable activity for our scopes (around 0.1 - 1 Bq). The situation will even improve in the following years.

This ^{224}Ra "secondary" source so prepared is particularly interesting because there are 5 α decays involved before reaching the stable nucleus of the chain (^{208}Pb).

Nuclide	**Decay**	**Half-life**	**Main α E [MeV]**
^{232}Th	α	1.405×10^{10} y	4.081
^{228}Ra	β	5.75 y	----
^{228}Ac	β	6.25 h	----
^{228}Th	α	1.9116 y	5.340 5.423
^{224}Ra	α	3.66 d	5.685
^{220}Rn	α	55.6 s	6.288
^{216}Po	α	0.145 s	6.778
^{212}Pb	β	10.64 h	----
^{212}Bi	α 35.94% ß 64.06%	60.55 min	6.051 6.090 ----
^{212}Po	α	299 ns	8.784
^{208}Tl	β	3.053 min	----
^{208}Pb	stable		

We can thus have 6 monochromatic α at 5.7, 6.05, 6.1, 6.3, 6.8 and 8.8 MeV, with an almost perfect distribution for a good calibration in energy of our bolometers response. The implantation will be very superficial, which will guarantee a very narrow intrinsic width of the peaks. In fact, the ^{224}Ra nuclei that should escape from the ISOLDE source and be implanted in our foils would have, at most, the kinetic energy that comes from the alpha decay, which is of the order of 100 keV that in Cu, for instance, would correspond to an implantation depth of only 15 nm. We will therefore be able to understand the behaviour of our bolometers to α of different energies and we will be able to study any energy smearing that could appear in our data as due to the crystal surface characteristics, since no important contribution to that phenomenon should come from the source itself.

The implanted foil would be positioned just in front of the bolometer under study and cooled down to 10 mK aprox. in less than a week. Since ^{224}Ra half life is 3.66 d, the activation of the foil would decrease but it will still be useful for a 1-2 weeks run time, which is our typical running time for R&D tests on our bolometers.

The ISOLDE source would then be used to activate new foils, whenever a cryogenic measurement will be required, for several years.

4 ISOLDE beam-time request

To produce ^{228}Ra, we ask for a UC target with surface ionizer. The yield available in the ISOLDE database is 1.8e7 ions/μC (from SC data) and we assume here to get the proton current of at least 1μA.

We ask for complete support in the preparation of the source, since we do not have any expertise in the beam or in the collector or target material preparation and handling.

5 Conclusions

It's incredible how Nature has prepared such a configuration that matches so well so many different requirements, some of which seem even to be in contrast one with the other:

1) We ask for a very shallow depth deposition of an α radioactive source on a host material. ISOLDE can do this for us thanks to its ion beams

2) We want to prepare a low activity source in a reasonable time (not millisec, but also not several days or more). ISOLDE can produce a 5 kBq ^{228}Ra source in 24h. It's not too small activity, it's not too high, it needs a reasonable time to prepare it

3) We're looking for a source for our lab that will last at least for some years: ^{228}Ra has a 5.7 y half-life. Not too long, not too short...

4) We cannot work with too high activity with our bolometers, but we need a multi-α source for calibration and other energy studies that should last at least few weeks: since ^{228}Ra is part of a radioactive chain we're able to have a reasonable long living isotope (^{228}Th) that will implant for us a "well tuned" multi-α source with very low activity but lasting long enough (luckily enough, ^{224}Ra has an half-life of 3.66 d).

5) the surface implantation will be at an even more shallow depth, since it will come just from the kinetic energy of the ion from the decay (97 keV)

Really a perfect source...

Summary of requested shifts:

3 shifts to implant up to 5 kBq of ^{228}Ra.

References:

[1] N. Booth,B. Cabrera, E. Fiorini, Ann. Rev. of Nucl. and Part. Sci. 46 (1996) 471;

C. Enss (Ed.), Cryogenic Particle Detection, Series: Topics in Applied Physics, 99 (2005), Springer; Proceedings of LTD15, Low Temp J 176 (2014)

[2] D. R. Artusa et al., AHEP (2014), Article ID 879871, in press.

[3] A. Alessandrello et al., PLB **408** (1997) 465 [QF]

[4] F. Bellini et al., JINST 5 (2010) P12005

[5] C. Arnaboldi et al., Astrop. Phys **34** (2011) 797

[6] D.R. Artusa et al., Euro. Phys. J C **74** (2014) 3096

[7] M. Vanzini et al., NIM A **461** (2001) 293

[8] Isotrak Catalogue and M. Imbriani, Campoverde Srl, private communication

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment)*

Part of the Choose an item.	Availability	Design and manufacturing
SSP-GLM chamber	☒ Existing	☒ To be used without any modification

HAZARDS GENERATED BY THE EXPERIMENT

Hazards named in the document relevant for the fixed SSP-GLM chamber installation.

Additional hazards:

Hazards			
	GLM	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum	1e-6		
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	UC		
Beam particle type (e, p, ions, etc)	228Ra		
Beam intensity	2e7 ions/sec		
Beam energy	10 kV		
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope	228Ra		
• Activity	5 kBq		
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		

Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

No additional equipment used in the experiment